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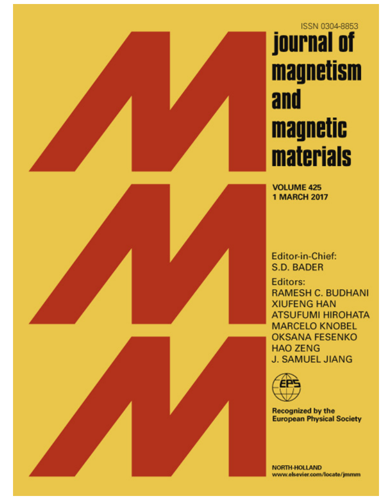


Research articles

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# Magnetic Behaviour of Assemblies of Interacting Cobalt-Carbide Nanoparticles

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**Abstract:** Recent work [1] demonstrated high coercivity and magnetic moment in cobalt carbide nanoparticle assemblies and explained the high coercivity from first principles in terms of the high magnetocrystalline anisotropy of the cobalt carbide nanoparticles. In this work, we comprehensively model the interaction between the nanoparticles comprising the assembly and systematically understand the effect of particle size, distribution of the orientations of the nanoparticles' magnetocrystalline anisotropy axis with respect to the applied magnetic field, and dipole coupling between nanoparticles on the temperature dependent magnetic behavior of the nanoparticle assembly. We show that magnetocrystalline anisotropy alone is not enough to explain the large hysteresis over the 50K-400K temperature range and suggest that defects and inhomogeneity that pin the magnetization could also play a significant role on this temperature dependent magnetic behavior.

## 1. Introduction

Permanent magnets are used in an increasing number of applications and are typically alloys that have 4f elements (rare earth materials). These 4f elements lead to both high magnetic moment and high magnetocrystalline anisotropy that result in properties desirable in permanent magnets: high remanence and high coercivity [2]. However, the mining process for rare earth materials is detrimental to the environment, their yield is low and their extraction cost is high [3]. This motivates research on rare earth free permanent magnets with high coercivity and high magnetic moment.

One way to make such permanent magnets is by employing exchanged-coupled hard and soft magnetic material, which is known as 'exchange-spring magnet' [4]. Exchange spring magnets have high coercivity and high magnetic moment due to exchange interaction between a hard magnetic material (whose moment may not be very high) and a soft magnetic material with high magnetic moment. Thus, exchange spring magnets that have low rare earth material content (<15% hard magnetic layer) in combination with an exchange coupled high magnetic moment soft layer can exhibit the desirable properties of hard magnets [5]. Furthermore, by coupling an extremely hard FePt phase layer [6] with a soft high moment $Fe_3Pt$ phase layer, rare earth free hard magnets can be synthesized [7].

Another approach is the development of core-shell magnetic particles [8], [9]. The authors synthesized Co/CoO nanoparticles where exchange bias between the central soft ferromagnet Co with high magnetic moment and the surrounding antiferromagnetic oxide CoO greatly enhances the magnetic anisotropy of the core-shell system while retaining high magnetic moment. These nanoparticles have a blocking temperature close to room temperature 290K and coercivity of 0.59 T while exhibiting high saturation magnetic moment [8] .